Convection and Shear Flow in TC Development and Intensification

C.-P. Chang
Department of Meteorology
Naval Postgraduate School, Code MR/Cp
Monterey, CA 93943
Telephone 831-656-2840, e-mail cpchang@nps.edu

H.C. Kuo
Department of Meteorology
Naval Postgraduate School, Code MR/Cp
Monterey, CA 93943
Telephone 831-656-2840, e-mail kuo@lanczos.as.ntu.edu.tw

C. H. Liu
Department of Meteorology
Naval Postgraduate School, Code MR/Cp
Monterey, CA 93943
Telephone 831-656-2840, e-mail ching_hwang@yahoo.com

LONG TERM GOALS

To study the dynamic processes of tropical cyclone (TC) development in the western North Pacific through field observational data and theoretical modeling.

OBJECTIVES

The objectives are: (1) to study the convection and vorticity generations in the vortex environment that may lead to the development and intensification of tropical cyclone; (2) to study the development and evolution of deep moist mesoscale convective system subject to strain effect due to the horizontal shear associated with the vortex rotation; (3) to study the offsetting between (1) and (2); (4) to study nonlinear interactions that may lead to additional strain effects that may impact on the convection in ways that are not yet known.

APPROACH

We participated in the field phase in summer 2008. In 2009, our main effort was to analyze the Eldora radar data especially focusing on the case of Typhoon Sinlaku. In the past, the filamentation time was discussed only in theoretical studies. In this research, the filamentation time was analyzed using the high resolution wind retrieved from the NRL P-3 radar. The results are used to study the relationship between filamentation and convection.

1. REPORT DATE **2009**	2. REPORT TYPE	3. DATES COVERED **00-00-2009 to 00-00-2009**
4. TITLE AND SUBTITLE **Convection And Shear Flow In TC Development And Intensification**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Postgraduate School, Code MR/Cp,Department of Meteorology,Monterey,CA,93943**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT   **Approved for public release; distribution unlimited**

13. SUPPLEMENTARY NOTES

14. ABSTRACT   **To study the dynamic processes of tropical cyclone (TC) development in the western North Pacific through field observational data and theoretical modeling.**

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

WORK COMPLETED

The data for this study is collected by the NRL P-3 aircraft near typhoon Sinlaku 2008 (W15, 2008), which became a named typhoon on 00Z, Sept 9, 2008. It reached its maximum intensity on 18 UTC, Sep. 10 with maximum wind up to 125 knots and minimum center pressure 929 hPa. Then it slowly weakened with wind speed dropping to 35 knots on 00 UTC, Sep. 17. Afterwards, it began its second phase of intensification with the maximum wind reaching 70 knots and minimum SLP pressure 970 hPa on 06 UTC 19 Sep.

NRL P-3 aircraft (research flight #14m RF014) sampled the outer and inner rainband around 02 UTC on 18 Sep (Fig 1). The P-3 approached the rainband from eastern side of Sinlaku then counterclockwise circled to the northern and western portions, finally broke out of the rainband at the southwestern side of the typhoon. The P-3 spent about 20 minutes on this 3/4 part of the entire circulation and collected valuable data for this study. Using the dual-Doppler technique, the three-dimensional wind field on both sides of the flight track was obtained wherever there was echo. Fig. 1 shows the radar reflectivity superimposed with the retrieved wind and flight track at 1 km horizontal resolution. In this figure only every sixth vector is plotted. The reflectivity pattern showed several rainband associated with the typhoon and wrapped into the center transferring the moisture flux into the inner eye wall. At the ranges between 41 and 51km, a rainband which seemed to be standing along without wrapping directly into the center was used to compute the filamentation time.

Rozoff et al. (2006) theorized that the formation of a moat region between concentric eyewalls may be partially caused by the strong filamentation effects associated with large core vorticity. In the past, only synoptic scale data were available to study the characteristic of the time scale for growth. The high-resolution NRL P-3 dual-Doppler radar observations provided a unique opportunity to calculate this time scale. The filamentation is defined as

$$\tau_{fli} = \begin{cases} 1/\sqrt{S_1^2 + S_2^2 - V^2}, & \text{if } S_1^2 + S_2^2 - V^2 > 0 \\ 0, & \text{if } S_1^2 + S_2^2 - V^2 < 0 \end{cases},$$

where $S_1 = \dfrac{\partial u}{\partial x} - \dfrac{\partial v}{\partial y}$, $S_2 = \dfrac{\partial v}{\partial x} + \dfrac{\partial u}{\partial y}$, and $V = \dfrac{\partial v}{\partial x} - \dfrac{\partial u}{\partial y}$ are stretching deformation, shearing deformation and vorticity, respectively. These terms are computed using the dual-Doppler radar wind at each grid point.

RESULTS

Figure 2 is the distribution of radar reflectivity with respect to filamentation time within 51 km range at different heights from the sea level. From the lower level to higher level, the red contours showed max frequency near 30-35 dBZ and filamentation time around 15 minutes, although the time scale may range to about 60 minutes. Figure 3 is the normalized filamentation time at the same dBZ bin. These results suggest:

(1)   several spiral rain bands with high reflectivity are found to wrap into the center, possibly transporting the enthalpy flux into the inner eye wall;

(2) existence of rapid filamentation zone (i.e., filamentation time smaller than 30 min) in a region between radius of 5 km and 50 km;

(3) of all the data analyzed, the filamentation time, the vorticity field, and the vertical motions are well correlated positively with the convective dBz values;

(4) within the radius of 50 km, the filamentation time (the deep convection dBz counts) in general increases with the radius from the typhoon center;

(5) large (small) variability of radar reflectivity dBz counts is observed in the region of small (large) filamentation time; the large variability of dBz in rapid filamentation zone may be an indication that some deep convections are weakened by the filamentation dynamics (shear deformation).
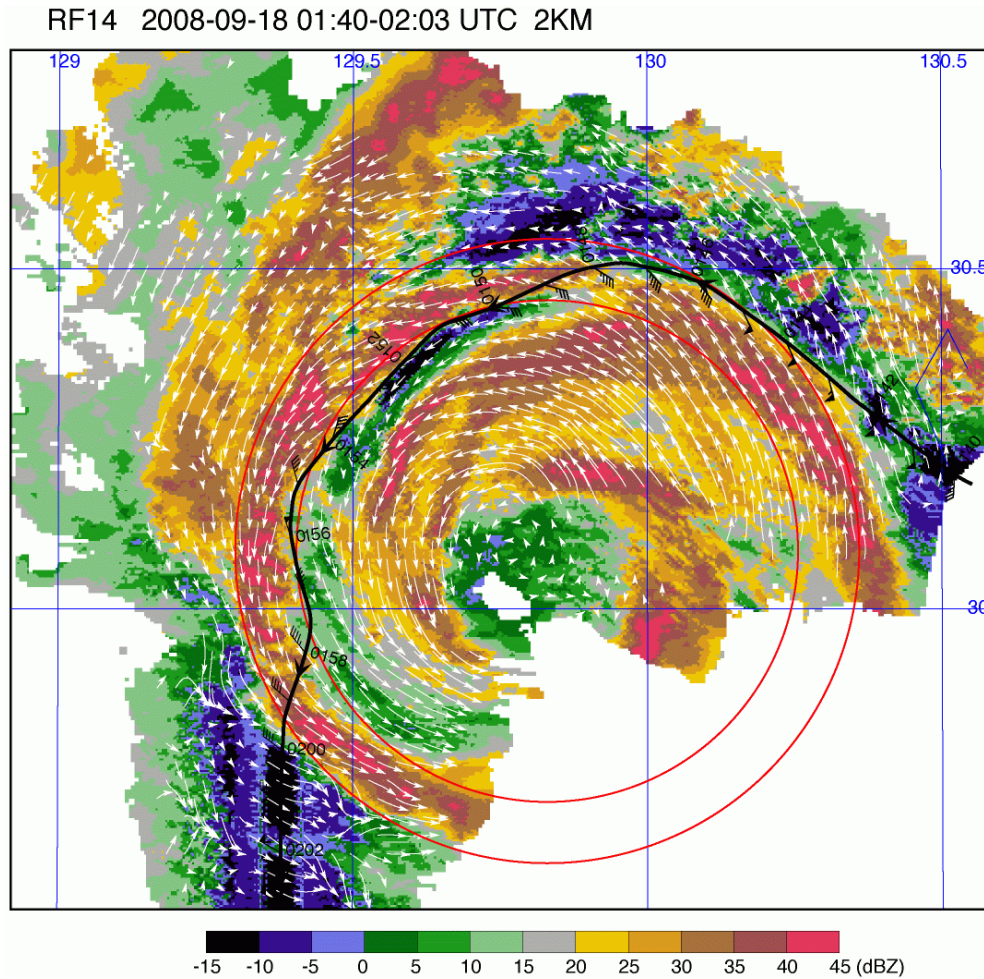

Fig 1. NRL P-3 radar reflectivity (color background) and dual-Doppler derived wind (white) at flight level or typhoon NRRI on 2008-09-18. Black line is the P-3 flight track. The two red circles indicate the ranges of 41 km and 51 km, respectively, from the cyclone center.
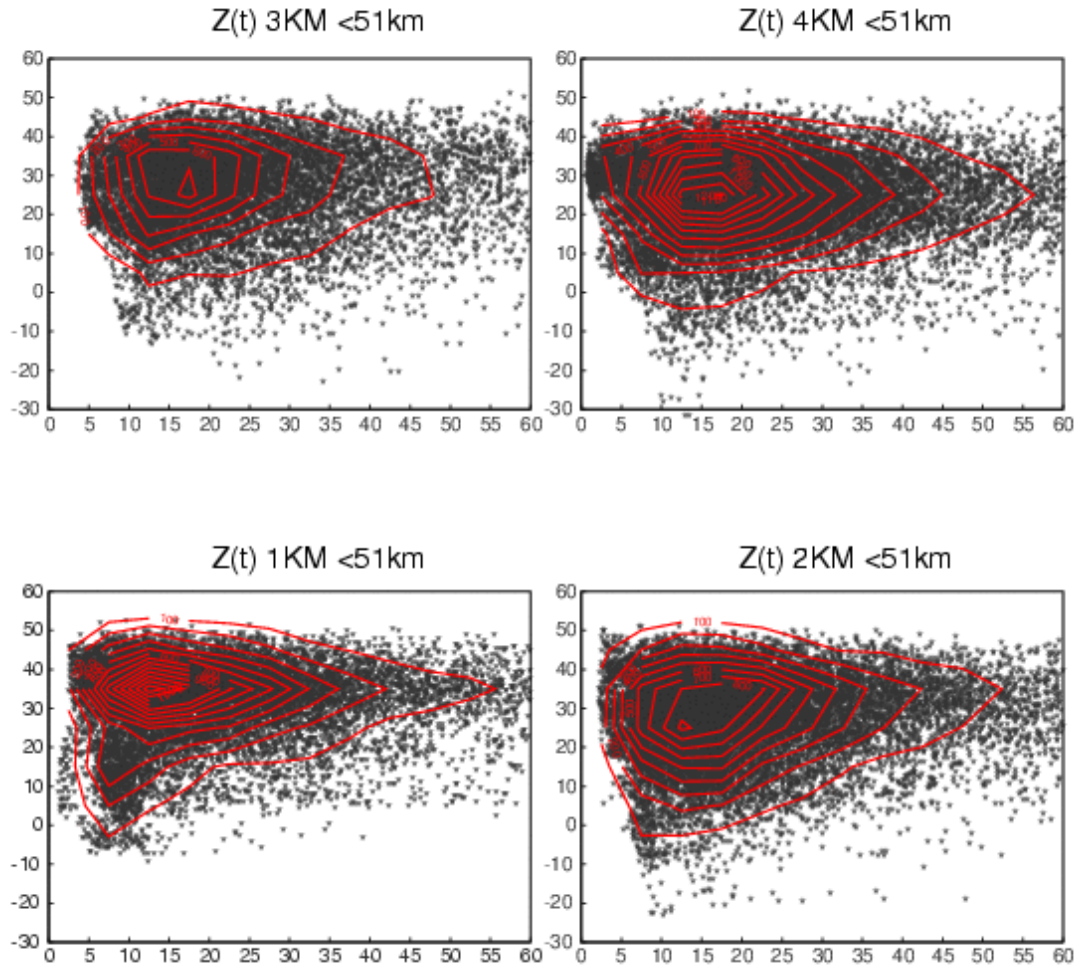
Fig 2. Scatter plot of radar reflectivity (y axis, dBZ) with respect to filamentation time (x axis, minute) at 1 km, 2 km, 3 km and 4 km above the sea level. Red lines are the contours of frequency. All data within 51 km from the typhoon center are plotted.
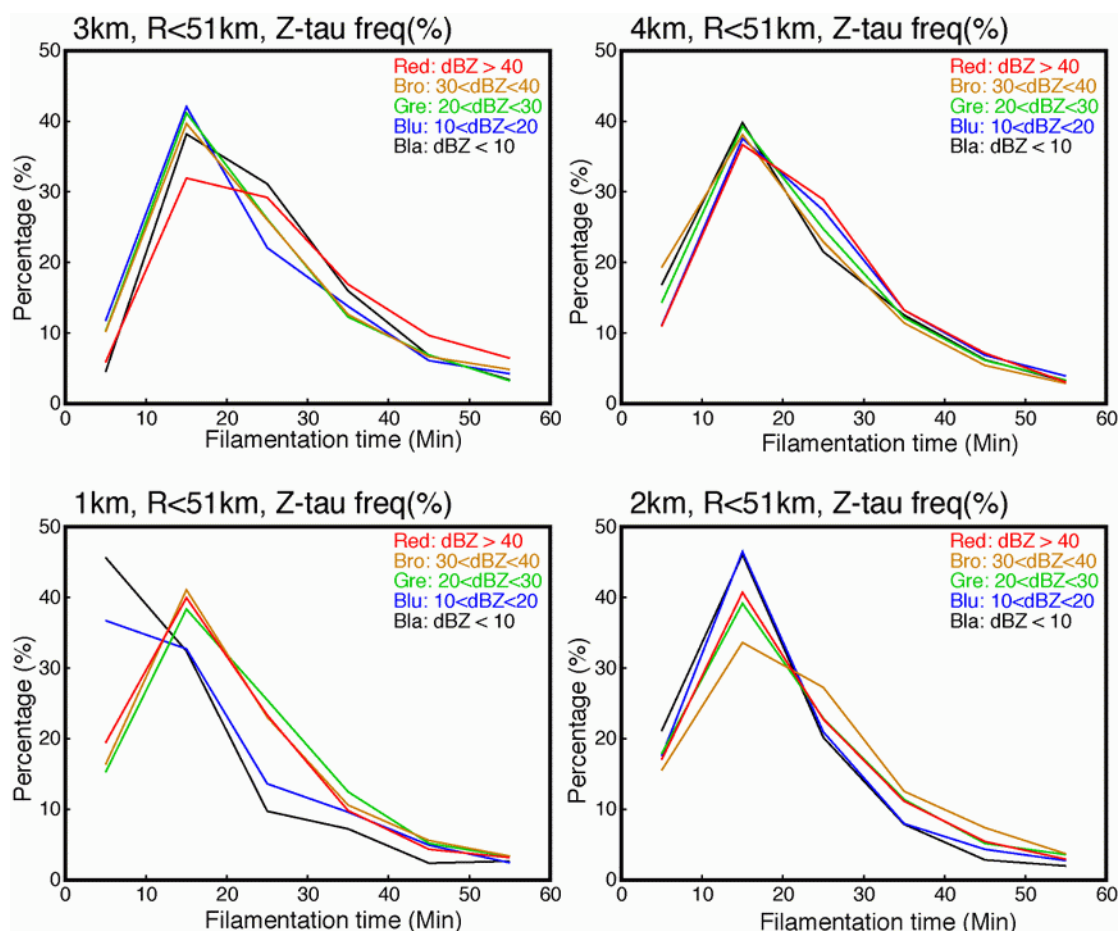
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Fig 3. Normalized percentage of frequency distribution vs. filamentation time of a dBZ bins at different height corresponding to Figure 2

IMPACT

Previously, the theoretical filamentation time for convection in a tropical cyclone can only be inferred crudely from synoptic scale data. This was the first time the filamentation growth rate is computed directly from high resolution winds that were derived from the NRL P-3 dual-Doppler radars observations in the field phase of TCS-08.

RELATED PROJECTS

TCS08 project led by Professors Russ Elsberry, Pat Harr and Michael Montgomery at NPS..

SUMMARY

The TCS-08 P3 radar data were used to compute the theoretical filamentation time from the non-divergent barotropic equation, with the results indicating that the filamentation process may indeed weaken some deep convection as predicted by certain theories.

PUBLICATION

Kuo, H.-C., C.-P. Chang, Y.-T. Yang and H.-J. Jiang, 2009: Western North Pacific Typhoons with Concentric Eyewalls. *Mon. Wea. Rev.* (accepted)